EFFECTIVE DESIGN OF AUDITORY DISPLAYS: COMPARING VARIOUS OCTAVE RANGES OF PITCH AND PANNING

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ABSTRACT

There is a large volume of research on designing effective visual displays, however there is little empirical research informing basic design on auditory displays. With the decreasing size of hardware (e.g., hand-held devices) and the increasing amount of software available, auditory displays are viable option for communicating data in places that have limited space for visual displays and for eye-busy environments. Auditory graphs are auditory displays that map quantified data to acoustic dimensions, such as pitch and panning, to represent changes in data. In the present study, we investigate the octave range of pitch that most effectively represents the data in an auditory graph, as well as the effects of utilizing the acoustic dimension panning to give participants added temporal context. Significant results were found that support the use of panning. A significant interaction between the reported maximum temperatures and octave range, as well as a significant main effect was found for the type of statistic participants were asked to report (minimum value, maximum value, and average value), these results are discussed.

1. INTRODUCTION

With the explosion of new technologies in the twenty-first century, many people have to learn how to interpret a large volume of information presented through both visual and auditory displays. The implementation of auditory displays not only enhances the effectiveness of various technologies, but also is crucial for individuals with visual impairments, and for people working in eye-busy environments [1,2,3]. Because of this, it is important to investigate how sound patterns can augment and even replace visual displays in communicating quantitative information [4]. Auditory display designers are in need of basic rules and guidelines to reference when designing an effective display, rather than relying on intuition or replicating what has been used in the past. Sándor et al. [5], mentions that designers have several crucial decisions to make regarding what data to represent, how to represent the data, and what dimensions to use. As Barrass [6] pointed out, many of the designers working on new technologies have little understanding and knowledge about making an effective auditory display, so having some basic rules and guidelines would be beneficial so that they can be referenced when needed and reused to guide other projects.

Since the inception of the Graphical User Interface (GUI), design guidelines for visual displays have become relatively well established [1] and while strides have been made in the research of auditory displays, there remains a lack of empirical research to help guide the design process [4,7,8,9].

Peres [1] identified four categories in which auditory displays are used: (1) presenting information to visually impaired people (2) providing an additional information channel for people whose eyes are busy attending to a different task (3) alerting people to error or emergency states of a system, and (4) providing information via devices with small screens such as PDAs or cell phones that have limited ability to display visual information. For the purpose of this study, we focused on auditory graphs, an auditory display classified as data exploration that uses sound to represent quantitative data [8,10]. An example of an auditory graph is when Flowers [4] mapped temperature ranges for each month to a pitch. Flowers [11] found that weather data makes for a compelling auditory display format partly because of its sequential observation across time. Auditory graphs can grant the visually impaired the same benefits that visual graphs offer to sighted individuals, such as a concise summary of data, and trend analysis [12]. Research has also found that the use of auditory graphs is an opportunity to teach statistical concepts like central tendency, variability and shapes of distributions to both sighted and visually impaired individuals [4]. Further, Peres and Lane [13] used sound dimensions to communicate statistical information usually contained in box plots.

Much of the research on auditory displays has examined the impact of these displays on attention, cognitive load, and discrimination from distracters and less on the structure and guidelines for making an effective display [14,15,16,17]. Although there is some research that has investigated acoustic dimensions in attempt to determine which dimensions are most effective in the interpretation of auditory displays, more is still needed. The acoustic dimensions previously studied include: pitch, loudness, timbre, tempo, and panning [1]. In the research presented here, we chose to focus on two dimensions: pitch and panning. Pitch is the most widely used dimension but its level of effectiveness varies depending on the context of the experiment, as a result, more research is needed to further design guidelines [10,13,18,19]. According to Flowers [20], "mapping pitch height (log frequency) to numeric magnitude affords perception of function shape or data profile changes, even for relatively untrained observers". Walker and Nees [10] found pitch to be a good option for representing temperature data. Until the current study the research conducted on pitch has not tested which pitch ranges result in the most accurate interpretation of the data. Flowers [4] stated that additional research could help determine optimal pitch ranges for auditory graphs.

Panning is a mapping technique that presents sounds in a manner so the listener perceives the sounds spatially. It is conceivable that if this dimension were used redundantly with time to represent information on an auditory graph that people's comprehension of the graph could be improved [10]. However, panning has been studied even less than pitch and thus there is currently no empirical data to support this position. Peres and Lane [13] found pitch to be only slightly more effective than pitch mapped redundantly with panning in the presentation of box plots. Interesting, users preferred the redundant condition (pitch with panning) strongly to pitch or panning alone. However, panning mapped redundantly with other dimensions has not been investigated empirically.

In order to test the effects on performance when pitch and panning are used for auditory displays, we used these two dimensions to build different auditory graphs that display temperature data. Specifically we wanted to explore how octave range and panning impacted people's ability to interpret different statistical elements in the data, e.g., trend, mean, range, etc.

2. METHOD

2.1. Participants

59 participants (43 females and 16 males) were recruited for this study. The mean age was 30.34 (SD= 10.56). Each subject served in a single experiment session. All participants were screened by self-report to ensure normal or corrected-to-normal hearing.

2.2. Stimuli

Twelve auditory graphs were created from two sets of temperature data using Sonification Sandbox 5. Each of the two data sets used consists of the recorded high temperatures in a geographical area for a one month period, or 30 days, for a total of 30 data points. The weather data used for the data sets was taken from the Weather Channel website [21]. All of the auditory graphs last 20 seconds and consist of 30 discrete sounds—each sound representing a single data point in the data set. To control for practice effects, each participant was exposed to two auditory graphs, each constructed using a different data set.

Six "pitch-only" auditory graphs were made from a single data set by mapping the temperature data value to pitch. The chromatic scale was used so each octave consists of 12 pitches. For example, an auditory graph made from the first octave range listed below (C3) would consist of the following 12 pitches: C3, C#3, D3, D#3, E3, F3, F#3, G3, G#3, A3, A#3, B3.

For the current study, different octave "ranges" were used to map the temperature data to sound. The octaves used are listed below. Each octave contains 12-notes and the number in parentheses indicates the frequency of the first note in the octave:

- C2 (65.406 Hz)
- C3 (130.813 Hz)
- C4 (261.626 Hz)
- C5 (523.251 Hz)

Thus, there were three different "octave range" designs: a single octave designs (2 of the designs), two-octave designs (3 of the designs), and one 4-octave design. The composition of each of these is listed below:

Single Octave ranges

- C3
- C4

Two Octave ranges

- C2 and C3
- C3 and C4
- C4 and C5

Four Octave range

- C2, C3, C4 and C5

These octave ranges were chosen because they are appropriately varied for the scope of this experiment as there is little consensus with regard to the best pitch ranges to use for auditory graphs [4]. Additionally, the octave ranges chosen are neither too high nor too low, so as to avoid having two distinct pitches that a participant with normal hearing might not be able to discern as different.

There were two data sets used to create the panning and non-panning auditory graphs. One set was mapped to the pitch-with-panning auditory graphs and the other was mapped to the pitch-only auditory graphs. The pitch-with-panning auditory graphs use the same pitch ranges listed above, but also had panning redundantly representing time. To create a "panning effect" the loudness of each sound was manipulated so that the sounds seemed to move through the listener's skull from left to right. The sound representing the high temperature for the first day of the month, the first data point, seems to emanate from a source at the left ear, the sound representing the middle data point seems to emanate from a source between the participants ears, and the sound representing the last point seems to emanate from a source near the right ear.

2.3. Procedure

Participants were given a brief orientation about the auditory graphs they would hear and the surveys they would complete. The orientation was presented on a HTML document that the participants progressed through with the researcher providing additional instructions.

After participants finished the orientation they were prompted with a "tuning page" that preceded each of the two auditory graphs. The purpose of the tuning page was to inform participants of the specific temperature-pitch relationship that was used in the auditory graph. Specifically, participants listened to a sound clip in which a series of three different tones were played and the temperature values of each tone were concurrently displayed visually on the computer screen. This temperature-pitch relation was the same used for both of the auditory graphs the participant hears. The tuning page also provided information about the measures participants completed after listening to the auditory graph.

Each participant listened to two auditory graphs, one pitch-only auditory graph and one pitch-with-panning auditory graph. Both of these auditory graphs used the same octave range. After listening to the first auditory graph participants gave responses about the statistical properties of the data they heard (minimum, maximum and average) and their subjective ratings of the sounds. After providing information about the first graph, participants would then be presented with the tuning page for the next auditory graph. They would listen to a corresponding auditory graph that was followed by the same tasks and subjective ratings. After the second rating was completed, participants were debriefed. For all participants the order in which participants listened to the auditory graphs (i.e., panning, no panning) was counterbalanced.

2.4. Measures

Participants were given two short measures to complete after listening to each auditory graph. The performance measures were comprised of several questions used to determine the participants' understanding of the data presented in the auditory graph. Specifically, participants were asked to provide estimates of the minimum and the maximum temperature, as well as the mean temperature. A preference measure was also collected to determine the participants' subjective of how enjoyable, helpful, or distracting they found aspects of the auditory graphs to be.

To measure participants' performance, error scores were created by taking the difference of participants' responses on the performance measure and the respective true values of the temperature data sets. An error score closer to zero indicates a more accurate response. A negative error score indicates the participant reported a value lower than the actual value.

3. RESULTS

Error scores were analyzed in a 6 x 2 x 3 (6 octave ranges x 2 panning levels x 3 performance measures) factorial ANOVA. A significant main effect was found for panning, $F(1, 52) = 4.513$, $p = 0.038$. Overall accuracy of participants' responses on the performance measure was greater for auditory graphs with panning. As shown in Figure 1, error scores for the non-panning auditory graphs had were worse (mean of -5.54) than those for the panning auditory graphs (mean of -3.153).

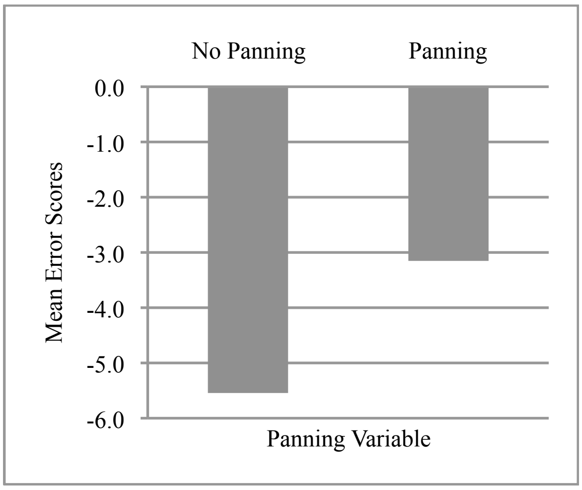

Figure 1: Mean error scores for performance responses for auditory graphs without panning and with panning.

A significant main effect was also found for performance measures, $F(2,104) = 13.207$, $p < 0.001$. Participants were more accurate in reporting the minimum temperature than the maximum or average temperature across all conditions. The mean of the error scores for reported minimum temperatures was 0.997, maximum was -7.445 and average was -6.598. This main effect can be seen in Figure 2.

Figure 2 also illustrates the significant interaction between octave range and performance measures, $F(10, 104) = 2.335$, $p = 0.016$. Participants' reported maximum temperatures were more accurate when they listened to an auditory graph with octaves ranges of C2-C3, C3-C4, C4-C5, or C2-C5. They were the least accurate in reporting the maximum temperature for the single octave ranges of C3 and C4. No significant main effect was found for octave range and all other interactions were not significant ($ps > 0.15$).

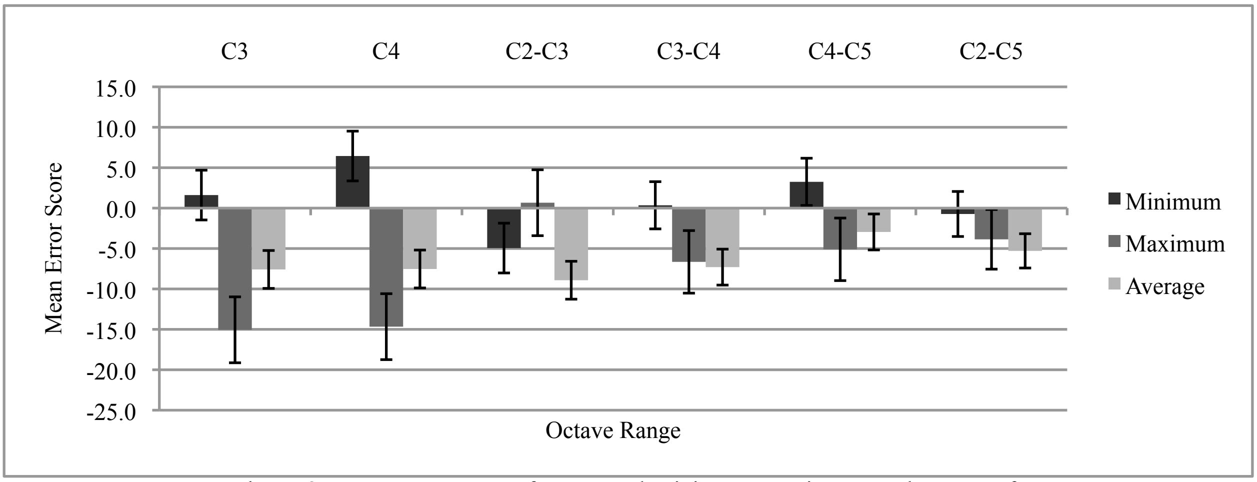

Figure 2: Mean error scores for reported minimum, maximum, and average for each octave range.

4. DISCUSSION

The significant main effect for panning suggests that panning yields additional context to the auditory graph when panning redundantly represented time. Panning possibly added relevant and useful information enabling the participants to more accurately interpret and understand the auditory graphs, irrespective of the octave ranges the auditory graph utilized. Auditory graph designers should consider utilizing panning to assist their users in interpreting the passage of time or anticipating the length of an auditory graph. More in depth research needs to be conducted with a focus on panning, as this research did not focus primarily on different applications of panning.

Across all conditions participants were more accurate when reporting the minimum temperature then either the maximum temperature or the average temperature. This is likely a function of the fact that participants generally underestimated the values they were asked to report (see Figures 1 and 2). Further, their accuracy could actually be due to the design of the "tuning page." The tuning page was used to introduce participants to the specific temperature-pitch relationship and one of the sample values used was 40. The minimum value in each data set was 33 and so participants were more familiar with a pitch near the minimum than the maximum. Similarly, the average required a much more complicated judgment to determine. It is also possible that low pitches are more distinguishable and understandable than higher pitches in the context of auditory graphs.

Participants were more accurate in reporting the maximum temperature for the auditory graphs that included more than just one octave range (e.g. C2-C3, C3-C4, C4-C5, C2-C5). This suggests that auditory graph utilizing multiple pitch ranges can improve performances in circumstances when users must report the maximum values of the data set.

The results from this study are important and intriguing, however, the effects and application of panning need more attention. Future research should more thoroughly investigate the effects of different octave ranges on interpreting auditory graphs, focusing on larger ranges. While this research suggests that larger pitch ranges may allow for more accurate interpretation of certain statistics,, the lack of a main effect of octave range (e.g. C2-C3, C3-C4, C4-C5 or C2-C5) may indicate that auditory graph designers have more freedom to choose what pitch ranges best fit their specific design.

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